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Description

[A Conduit Having a Cable Therein]

Cross Reference to Related Applications

[0001] This application claims the benefit under 35 U.S.C. §119(e) of U.S. Provisional Patent Application Serial No. 60/495,663, entitled "CONDUIT HAVING A CABLE THEREIN," filed August 15, 2003.

Background of Invention

[0002] The present invention relates generally to the field of cables, and more particularly to a device and method for providing a cable in a conduit.

[0003] An electric submergible pump (ESP) may be suspended in a well from coiled tubing with an electric cable to power the pump inside the coiled tubing. Produced fluid is pumped up the casing to coiled tubing annulus. Since the electric power cable has low tensile strength, the length of power cable that can be freely suspended in inclined tubing is limited. Therefore, the cable may be clamped, banded or strapped to the outside of the tubing at inter-

vals, as disclosed in U.S. Pat. No. 4,681,169, which is hereby incorporated herein by reference. Alternatively, the cable may be disposed within the coiled tubing, as disclosed in U.S. Pat. Nos. 4,336,415; 4,346,256; 5,145,007; 5,146,982; and 5,191,173, each of which is hereby incorporated herein by reference. Other typical arrangements for suspending an ESP on coiled tubing are disclosed in U.S. Pat. Nos. 3,835,929; 4,830,113; and 5,180,014, each of which is hereby incorporated herein by reference.

[0004] Several systems have been used to support the electric power cable inside coiled tubing for ESP applications. For example, some systems employ anchor devices spaced along the cable to frictionally restrain the cable to the cable bore (e.g., U.S. Pat. Nos. 5,269,377; 5,435,351; 5,821,452; 5,988,286; 5,992,468; 6,167,915; 6,479,752, each of which is hereby incorporated herein by reference). In another example, "dimples" provided in the coiled tubing wall mechanically support the cable (e.g., U.S. Pat. Nos. 6,062,265 and 6,143,988, each of which is hereby incorporated herein by reference). Yet another example uses cable bonding to the tubing bore during tubing manufacturing (e.g., U.S. Pat. No. 5,191,173, which is hereby incorporated herein by reference). Some systems

use a viscous fluid inside the coiled tubing to suspend the cable (e.g., U.S. Pat. No. 6,112,813, which is hereby incorporated herein by reference). Other systems use a dense fluid inside coiled tubing to "float" the cable (U.S. Pat. Nos. 5,906,242 and 5,996,689, each of which is hereby incorporated herein by reference).

[0005] Some systems for supporting power cable inside coiled tubing for ESP applications use helical buckling of the cable to frictionally restrain the cable to the tubing bore (e.g., U.S. Pat. Nos. 5,954,136 and 6,148,925, each of which is hereby incorporated herein by reference). In the system described in U.S. Patent No. 5,954,136, the cable is generally in tension when assembled at surface and some additional cable is fed into the conduit (e.g., coiled tubing) only after the conduit is suspended in the well. Such a procedure results in an assembly in which the bottom of the cable is heavily buckled while the upper portion of the cable is in tension. When additional cable is fed into the conduit, some buckling does occur at the upper end of the conduit, but this buckling may be generally loose. Additionally, at the mid-portion of the conduit, the cable may remain in tension and thus not buckle at all. Therefore, the system described in U.S. Patent No.

5,954,136 does not produce a uniform buckling along the length of the assembly. As a result, vibration of the assembly during use can reduce the anchoring friction below a critical threshold and cause the cable to progressively settle until a stable, tighter helix is formed. This may cause pull-off of the cable connector or other failure.

[0006] Accordingly, there is a need for a method and related components for disposing an electric power cable within a conduit, such as coiled tubing, which yields a uniform helix of cable along the length of the conduit and which may be performed at a surface location before the conduit or cable is deployed downhole.

SUMMARY OF INVENTION

[0007] In general, according to some embodiments of the present invention, a system is provided for supporting a cable within a conduit whereby the cable forms a generally uniform helix along the length of the conduit. In such embodiments, the cable is uniformly supported along the length of the assembly.

[0008] In general, according to other embodiments of the present invention, a method is provided for putting excess cable into a conduit at surface to enable the cable to uniformly form a helix in the conduit preventing the cable from ex-

periencing tension during deployment into the wellbore.

[0009] Other or alternative features will be apparent from the following description, from the drawings, and from the claims.

Brief Description of Drawings

[0010] The manner in which these objectives and other desirable characteristics can be obtained is explained in the following description and attached drawings in which:

[0011] Figures 1A-C illustrate a method for installing a cable in a conduit according to some embodiments of the present invention.

[0012] Figure 2 illustrates an embodiment of the cable and conduit of the present invention being deployed in a well.

[0013] Figures 3A-B illustrate additional methods of buckling the cable within the conduit while on or alternatively off the spool in accordance with the present invention.

[0014] Figures 4A-C illustrate a method of the present invention for pumping a cable in a conduit according to the present invention.

[0015] Figures 5 illustrates a method of the present invention for installing a cable in a conduit by oscillating a tubing reel.

[0016] Figure 6 illustrates a method of the present invention for installing a cable in a conduit by inserting the cable within

the conduit at the time of manufacture.

[0017] It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

DETAILED DESCRIPTION

[0018] In the following description, numerous details are set forth to provide an understanding of the present invention. However, it will be understood by those skilled in the art that the present invention may be practiced without these details and that numerous variations or modifications from the described embodiments may be possible.

[0019] In the specification and appended claims: the terms "connect", "connection", "connected", "in connection with", and "connecting" are used to mean "in direct connection with" or "in connection with via another element" and the term "set" is used to mean "one element" or "more than one element". As used herein, the terms "up" and "down", "upper" and "lower", "upwardly" and downwardly", "upstream" and "downstream" "above" and "below" and other like terms indicating relative positions above or below a given point or element are used in this description to more

clearly describe some embodiments of the invention. However, when applied to equipment and methods for use in wells that are deviated or horizontal, such terms may refer to a left to right, right to left, or other relationship as appropriate.

[0020] For the purposes of the present discussion, the methods and related components of the present invention will be described for example as relating to suspending an electric submergible pumping system ("ESP") on a conduit within a wellbore. It should be understood, however, that any type of conduit, tube or pipe can be used, such as coiled tubing, jointed tubing and the like, to suspend any type of wellbore equipment, such as logging tools, wireline tools, drilling tools, and the like, within a wellbore. Further, for the purposes of the present discussion, the methods and related components of the present invention will be described, for example, as relating to disposing an electric power cable within coiled tubing, which is connected to an ESP; however, it should be understood that the methods of the present invention can be used to disposing any type of cable, tube, conduit, cable, wire or rope within any type of conduit.

[0021] In general, the present invention includes systems and

methods for supporting a cable in a conduit. More particularly, the present invention includes systems and methods for installing an electrical power cable into coiled tubing at surface for suspending and deploying an ESP in a well.

[0022] According to an embodiment of the present invention, a system includes a conduit having a cable therein wherein the cable defines a generally uniform helix or arcuate path along substantially the entire length of the conduit. Thus, the cable is uniformly supported along the length of the assembly. To accomplish the uniform distribution of the cable in the conduit, the cable is inserted into the conduit at the surface and is buckled along substantially its length before the conduit is deployed in the well. This helix or arcuate arrangement may be accomplished if sufficient cable slack beyond the unstretched length of the coiled tubing is uniformly installed in the tubing on surface. The cable may be buckled to define the helical or arcuate path while the coiled tubing is spooled, or alternatively as the coiled tubing is un-spooled on surface.

[0023] The present invention also includes a method of putting excess cable into the coiled tubing at surface -- rather than downhole -- to enable the cable to uniformly form a

helix or arcuate path in the tubing. To achieve this uniform helical or arcuate shape, a cable longer in length than the conduit must be used. However, by forming the helix or arcuate path, the entire length of the cable is in substantially a compressed state, thus preventing the cable from experiencing tension during deployment into the well.

[0024] For example, a conduit for suspension within a well may comprise a length of coiled tubing and a cable disposed within the tubing where the unstretched length of cable inside the tubing is longer than the tubing by at least approximately 0.5 feet per 1000 feet of tubing. The surplus cable is generally uniformly distributed along substantially the entire length of the conduit so that the cable defines a uniform helical or arcuate path inside the conduit before suspension in the well. By buckling the cable at the surface to form the helix or arcuate path, the tension observed by the cable during deployment may be less than 25 percent of the cable's tensile strength.

[0025] To achieve the uniform distribution of cable within the conduit in accordance with the present invention, a variety of method may be employed. One method of installing the cable, illustrated in Figures 1A-C and 2A-C, is to pump

the cable into conduit. U.S. Pat Nos. 5,503,370; 5,573,225; 5,599,004; and 5,699,996 show various methods for pumping cable into conduit. However, in accordance with some embodiments of the present invention, once the cable is fully inserted into the conduit, a selected additional length of cable is pumped into the conduit to achieve the desired buckling and uniform distribution of cable in the conduit. In determining the amount of additional cable to pump into the conduit, one or more of the following factors may be considered: (1) the length, diameter, materials, and material properties (e.g., maximum allowable compressive/tensile stress) of the cable and conduit; (2) the coefficient of friction between the cable and conduit; (3) the surface tensile and/or compressive stresses; (4) the expected change in the conduit and cable when subjected to well conditions (e.g., change in conduit length due to temperature change such as in thermal expansion/contraction); (5) the well deviation; (6) the use or presence of buoyancy fluids in the well; (7) the tubing permanent growth (i.e., the elongation of the tubing during each trip downhole due, for example, to gravitational forces); and (8) other factors.

[0026] As briefly described above, the present invention relies on

the concept of sizing the inside diameter of the conduit (such as coiled tubing), and the diameter of the cable (such as an electric power cable), and choosing the internal strength or stiffness of the cable, all so that the cable will purposefully "buckle" within the conduit, and thereby be frictionally locked into position. As used herein the term "buckle" means having the cable 28 change its longitudinal alignment under compression from being coaxial with the conduit 30 to being a sinusoid, spiral, helix or other arcuate shape, as generally shown in Figure 1, with the cable 28 contacting an interior surface 32 of the conduit 30 at a plurality of spaced longitudinal locations 34. The cable buckling causes the weight of the cable 28, between the points of contact 34 with the conduit 30, to be transferred as a compression frictional force to the conduit. This frictional force prevents the cable 28 from further downward longitudinal movement within the conduit 30, and so the cable becomes self suspending within the conduit.

[0027] The concept of "buckling" of the electric cable is meant as a purposeful, designed arrangement, and not as the well-known phenomenon of having the cable being damaged either by free suspension or excessive compressive forces.

It is well known to those skilled in the art that if a cable is held at the earth's surface and then allowed to be freely suspended within a wellbore, that the weight of the cable itself is greater than the internal strength of the cable to resist internal damage to the copper conductors and the insulation. Therefore, as mentioned previously, cable in the past has been banded or strapped to the outside of a conduit at intervals, such as every twenty (20) feet, or a plurality of internal cable anchors have been used to transfer the weight of the cable to the conduit. In the present invention, the cable is not freely suspended, but has its weight transferred uniformly to the conduit at the plurality of points of contact with the conduit.

[0028] Further, the term "buckling" includes the concept of carefully sizing the inside diameter of the conduit and the diameter of the cable, and choosing the internal strength of the cable so that the cable will purposefully form the desired sinusoidal, spiral, helical, or other arcuate shape and make the plurality of uniform points of contact with the interior surface of the conduit with sufficient compressive frictional forces to prevent downward longitudinal movement of the cable within the conduit.

[0029] With respect to Figures 1A-C, in some embodiments of

the present invention, the cable 100 (e.g., electrical power cable) is first pulled from a reel 104 into the conduit 102 (e.g., coiled tubing) while the conduit is arranged substantially horizontally (Figure 1A) at the surface. In some embodiments, a rope 106 may be attached to the cable 100 to facilitate pulling the cable into and through the conduit 102. This initial step causes the cable 100 to stretch due to friction between the cable and the conduit 102. The conduit 102 and cable 100 are then spooled onto a drum 110 (Figure 1B). A selected additional length of cable 100 is then pumped into the spooled conduit 102 until the desired length of cable and desired buckling and uniform distribution of the cable in the conduit is achieved (Figure 1C). In some embodiments, the additional length of cable 100 may be pumped into the spooled conduit 102 by providing a pumping unit 120 to push a carrying fluid through the conduit and into a return tank 122. The carrying fluid displaces the cable 100 into the spooled conduit 102.

[0030] With respect to Figures 2A-C, in other embodiments of the present invention, the cable 200 is pumped from a reel 204 into the conduit 202 while the conduit is arranged substantially horizontally (Figure 2A) at the sur-

face. A starting rod 206 may be attached to the cable 200 and pumped from an open end of the conduit 202 to a closed end by providing a pumping unit 220 to push a carrying fluid through the conduit and into a return tank 222 (Figures 2A-B). Once the starting rod 206 reaches the closed end of the conduit 202, a selected additional length of cable 200 is then pumped into the horizontal conduit 102 until the desired length of cable and desired buckling and uniform distribution of the cable in the conduit is achieved (Figure 2C). Finally, the buckled cable 200 within the conduit 202 may be spooled as shown in FIG. 1B.

[0031] Figures 3A-B each illustrate yet another embodiment of the present invention in which the cable 300 is buckled as the conduit 302 is pulled from the spool 310 (as shown in Figure 3A) or, alternatively, in the cable 330 is buckled while the conduit 332 remains on the spool 330 (as shown in Figure 3B). In the embodiment shown in Figure 3A, the cable 300 is arranged at or near the outer radius of the conduit 302 when the conduit is spooled. The unspooling and straightening of the conduit 302 causes the cable 300 to buckle uniformly in the conduit. By contrast, in the embodiment shown in Figure 3B, the cable 320 is already

buckled while the conduit 322 is on the spool 330.

[0032] With respect to Figure 4, in other embodiments of the present invention, insertion of the desired length of additional cable to achieve the uniform distribution of buckled cable in the conduit may be achieved by using an oscillating, vertically-oriented conduit reel 410 as shown in Figure 5. For example, systems for oscillating a conduit reel are described in U.S. Patent Nos. 5,946,788 and 5,950,298. In one embodiment, the cable 400 may be deployed into the vertically-spooled conduit 402 by a cable feed unit 406 to form a uniform, helical or arcuate arrangement within the conduit. Alternatively, in another embodiment, the cable 400 may be pumped into the vertically-spooled conduit 402 to form a uniform, helical or arcuate arrangement by pumping a carrying fluid from a pumping unit 120 to a return tank 122 as described above and illustrated in Figure 1C.

[0033] In still other embodiments of the present invention, the cable is installed in the conduit during manufacture of the conduit such that the desired extra cable is provided in the conduit at the time of manufacture. In this method, the desired length of extra cable and the desired buckling and uniform distribution of the cable in the conduit is

achieved during the manufacture of the conduit (e.g., coiled tubing). Published European Patent Application No. EP1094194 discloses one method of inserting a cable into a conduit during manufacture. With respect to Figure 5, a tube-forming mill 520 may be provided to form the conduit 502 from strip metal 503. A reel 504 for holding cable 500 may also be provided. A spool 510 is provided for storing the formed conduit 502 having a helical cable 500 therein.

[0034] Still with respect to Figure 5, in operation, the tube-forming mill 520 includes a set of rollers for bending the strip metal 503 into "U" shape and gradually into an enclosed tubular conduit 502 except for a longitudinal seam 505. The cable 500 is installed within the conduit 502 during the formation process from strip metal 503 to tubular conduit 502. A system of drive belts 550 may be used to shape the cable 500 into a helix or other arcuate arrangement as it is inserted into the bent strip metal 503. The helical cable 500 is installed uniformly along substantially the entire length of conduit 502. Once the cable 500 is installed, the longitudinal seam 505 is sealed at a welding station 530 and annealed at annealing furnace 540 to form the enclosed tubular conduit 502. The

conduit 502 with helical cable 500 within is then rolled onto spool 510 for use in well operations.

[0035] As illustrated in Figure 6, an electric power cable 600 supplies power to an ESP, which is suspend in a wellbore 608 on coiled tubing 602. The wellbore 608 penetrates one or more subterranean formations (e.g., hydrocarbon or water-bearing formations), and may include a wellhead 640 removably connected to an upper portion of a production tubing and/or casing string 650. If the casing string 650 extends across a fluid producing subterranean formation, then the casing string can include at least one opening or perforation for permitting fluids to enter the interior thereof. An electric submergible pumping system 660 is shown suspended within the casing string 650, and generally includes an electric motor, an oil-filled motor protector, and a pump. The ESP 660 is operatively connected to a lower end of a spool 610 of coiled tubing 602 that has been spooled into the casing 650. The coiled tubing 602 can be of any commercially available size (i.e. outside/inside diameter) and formed from any material suitable to the wellbore conditions, as all is well known in the art. For example, typical sizes of coiled tubing are from 0.75" OD to 3.5" OD, and are typically made from

steel alloys. The electric cable 600 is arranged within the coiled tubing forming a uniform helical (or "buckled") shape. A lower end of the electric cable 600 is operatively connected to the ESP 660 to provide electrical power to the electric motor, and an upper end is operatively connected at the earth's surface to electrical control equipment and a source of electrical power (both not shown).

[0036] In operation, the electric cable 600 is inserted into the coiled tubing to form a uniform helical or arcuate shape along substantially the entire length of the coiled tubing using one of the methods described above and illustrated in Figures 1-5. The lower end of the electric cable 600 is operatively connected to the ESP 660, suspended on coiled tubing 602, and run into the wellbore 608 to a production interval via a tubing injector 620 and injector guide 630. In some embodiments, a still further selected length of tubing cable ("pigtail") may be installed at the surface to accommodate any slight cable settling that may occur during downhole deployment. In one example, approximately 12-in per 1000-ft of pigtail is installed in the surface bonnet.

[0037] While embodiments of the present invention described herein may refer to "tubing" or "coiled tubing", it is in-

tended that other embodiments of the present invention exist for use with any conduit including, but not limited to, coiled tubing, jointed tubing, pipes, casings, liners, and other tubular goods. Also, while embodiments of the present invention described herein may refer to "electric power cable", it is intended that other embodiments of the present invention exist for use with any cable including, but not limited to electric power cable, fiber optic cable, hydraulic lines, or a combination thereof. Moreover, while the embodiments of the present inventions described previously include a cable defining a "uniform" or "substantially uniform" helical or arcuate path along the entire length of a conduit, any arcuate path will suffice as long as it spans substantially the entire length of the conduit. While a uniform helical or arcuate shape may be ideal, generally, the cable may form an arcuate path, which may include a reverse-spiral section and/or a section defining a tighter spiral than another section. For example, an embodiment may include a cable defining an arcuate path within a conduit where the cable is deployed in a tighter spiral pattern at the bottom of the conduit then at the top of the conduit. The key is that the cable defines any arcuate path through substantially the entire length of the

conduit to increase surface contact (and thus friction) within the conduit.

[0038] Although only a few exemplary embodiments of this invention have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the following claims. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures. Thus, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface, in the environment of fastening wooden parts, a nail and a screw may be equivalent structures. It is the express intention of the applicant not to invoke 35 U.S.C. §112, paragraph 6 for any limitations of any of the claims herein, except for those in which the claim expressly uses the words "means for" together with an associated function.